Chemistry 11 – Functional Groups Notes

So far we have investigated hydrocarbon alkanes and have found that this particular group has limited uses and properties. If all organic molecules were alkanes, then organic chemistry would be useless and boring!

Luckily, **specific groups of atoms** are found on organic molecules, which give the molecules more **specific properties** and **greater reactivity** with other compounds. These groups of atoms are known as **functional groups**.

- Functional Group: a specific group of atoms which exists in a molecule and gives a molecule an ability to react in a specific manner or gives it special properties

Functional groups may allow a molecule to:

- Act as an acid, a base, or both
- React with specific chemicals
- Have a particular solubility
- Have a pleasant or yucky smell
- Become explosive!

So far we have seen a couple of examples of functional groups present on hydrocarbons. They are the **carbon-carbon double bonds**, **carbon-carbon triple bonds**, and **halides**. We will now look at other important functional groups that are present in many everyday organic chemicals.

General Naming for Hydrocarbons Containing Functional Groups

The following molecules containing functional groups will be named according to these general rules:

1. **Find** the longest carbon chain containing the functional group. This chain determines the parent name of the compound.

2. **Change** the ending of the parent name to the ending specific to the functional group.

3. **Number** the parent chain from the end nearest to the functional group so that the functional group gets the lowest possible number. **Place** this number, along with a dash in front of the parent name.

4. **Identify** the side chains, **determine** the carbon number that they are attached to, and **name** them in alphabetical order.

Alcohols

- Alcohol: an organic compound containing an "**– OH**" group

- They have a general formula of $\mathbf{C_nH_{2n+1}OH}$

Properties of Alcohols

- High boiling and melting points (due to **hydrogen bonding** – the H from one OH group interacts with the O from another OH group)

- All alcohols are poisonous, yes…even ethanol!

- They are **polar** solvents (they have a specific positively charged end and a negatively charged end)

- Alcohols have two opposing solubility tendencies due to their structure:

  → The **polar OH** group tends to **interact** with water (which is also a polar molecule) making the alcohol **soluble**

  → The **non-polar hydrocarbon chain** tends to make alcohols **insoluble** in water

  → Therefore, **short-chained** alcohols tend to be more **soluble** in water such as methanol, ethanol, propanol, and butanol, while **longer** chains such as pentanol and higher are **insoluble**.

Naming Alcohols

- Use an ending of "**anol**" for the parent chain when naming alcohols

Example:

$$\begin{array}{ccccccc} \mathbf{1} & & \mathbf{2} & & \mathbf{3} & & \mathbf{4} \\ CH_3 & - & CH & - & CH_2 & - & CH_3 \\ & & | & & & & \\ & & OH & & & & \end{array}$$

← butanol parent chain

← alcohol OH group on Carbon-2

2-butanol

Example:

$$\begin{array}{ccccccccccc} \mathbf{6} & & \mathbf{5} & & \mathbf{4} & & \mathbf{3} & & \mathbf{2} & & \mathbf{1} \\ CH_3 & - & CH & - & CH_2 & - & CH & - & CH_2 & - & CH_3 \\ & & | & & & & | & & & & \\ & & CH_3 & & & & OH & & & & \end{array}$$

← hexanol parent chain

← 5-methyl and OH group on Carbon-3

5-methyl-3-hexanol

Carboxylic Acids

- Carboxylic Acid: an organic compound containing a "**– COOH**" group usually found on the end of a hydrocarbon chain

- The COOH group maybe shown as the following:

$$\begin{array}{c} \mathrm{O} \\ \| \\ -\mathrm{C}-\mathrm{O}-\mathrm{H} \end{array}$$

- They have a general formula of $\mathbf{C_nH_{2n+1}COOH}$

Properties of Carboxylic Acids

- High boiling and melting points due to hydrogen bonding

- They are polar molecules

- Can act as **acids** (usually referred to as organic acids)

Naming Carboxylic Acids

- Use an ending of "**anoic acid**" for the parent chain when naming carboxylic acids **(Note: the carbon in the COOH group is included in the parent chain!)**

Example:

$$\begin{array}{ll} \mathbf{2} & \mathbf{1} \\ CH_3 - & COOH \end{array}$$

← ethanoic acid parent chain with COOH group on Carbon-1 (the "1" can be **omitted** from the name of the chain)

Ethanoic Acid (commonly called Acetic Acid – found in vinegar!)

Example:

$$\begin{array}{llll} \mathbf{4} & \mathbf{3} & \mathbf{2} & \mathbf{1} \\ CH_3 - & CH_2 - & CH_2 - & COOH \end{array}$$

← butanoic acid parent chain with COOH group on Carbon-1

Butanoic Acid (the smell from smelly feet!)

<u>Esters</u>

- <u>Ester</u>: an organic compound which a "**– COO –** " group joins two hydrocarbon chains
- The COO group maybe shown as the following:

$$\begin{array}{c} O \\ \| \\ -\,C - O\,- \end{array}$$

- They have a general formula of $\mathbf{C_nH_{2n+2}COO}$

Properties of Esters

- They are good solvents (eg. Used in nail polish remover)
- Used to make polymers (long-chained molecules); found in fats, oils, and waxes
- Pleasant smelling; often used in foods and other fragrances

Ester	Odour	Ester	Odour
Ethyl butanoate	Pineapples	Pentyl propanoate	Apricots
Pentyl ethanoate	Bananas	Ethyl methanoate	Raspberries
Octyl ethanoate	Oranges	Methyl butanoate	Apples

Naming Esters (Note the following exceptions:)

- Use an ending of "**anoate**" for the parent chain when naming esters **(<u>Note</u>: You can omit the position of the COO group in the naming of the parent chain)**
- The hydrocarbon chain attached to the **carbon side** of the COO group is called the **parent chain**. The carbon in the COO group is also part of the parent chain!
- The hydrocarbon chain attached to the **oxygen side** of the COO group is named as an **alkyl group**. The name of this alkyl group exists as a **separate word** from the parent chain.

Example:

$$\underbrace{CH_3 - CH_2 - COO}_{\text{propanoate parent chain}} - CH_2 - CH_3 \quad \leftarrow \text{ ethyl group attached to O-side}$$

Ethyl propanoate

Example:

$CH_3 – COO – CH_2 – CH_2 – CH_3$ ← propyl group attached to O-side
----
|
ethanoate parent chain

Propyl ethanoate

Preparations of Esters

- Esters are made by reacting a **carboxylic acid** with an **alcohol** in the presence of an **acid catalyst** such as HCl or H_2SO_4. This process is known as an **esterification** reaction.

- The following is an example of preparing methyl ethanoate from ethanoic acid and methanol:

Ethanoic acid Methanol $\xrightarrow{\text{catalyst}}$ Methyl ethanoate Water

```
         O                                      O
         ||                            H+       ||
CH3 – C – O – H   +   HO – CH3         →   CH3 – C – O – CH3   +   H2O
```

The H from the acid and the OH from the alcohol are removed to form H_2O.

Ethanoic acid loses an H to become "ethanoate" in the ester. Methanol loses OH, to become a "methyl" group in the ester.

Try to name the products and draw the esterification reaction for each test tube in Lab 23B.

<u>Aldehydes</u>

- <u>Aldehyde</u>: an organic compound which has a "**– CHO**" group at the end of a hydrocarbon chain

- The CHO group maybe shown as the following:

```
  O
  ||
– C – H
```

- They have a general formula of $\mathbf{C_nH_{2n}O}$

Properties of Aldehydes

- Generally soluble in water due to hydrogen bonding
- Common aldehydes are liquids
- Distinctive odours (generally pleasant!)

Naming Aldehydes

- Use an ending of "**anal**" for the parent chain when naming aldehydes **(<u>Note</u>: the carbon in the CHO group is included in the parent chain!)**
- Since the CHO group is found on the **end** of a hydrocarbon chain, the **position** of the CHO group can be **omitted** from the parent chain name.

Example:

$$\begin{array}{ccccc} & & \mathrm{O} & & \\ & & \| & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{H} \end{array}$$

Methanal (commonly called Formaldehyde – Used as a preservative in biological specimens)

Example:

$$\begin{array}{cccccccccl} & & & & & & \mathrm{O} & & & \\ \mathbf{4} & & \mathbf{3} & & \mathbf{2} & & \| & & & \\ CH_3 & - & CH_2 & - & CH & - & C & - & H & \leftarrow \text{Butanal parent chain} \\ & & & & | & & \mathbf{1} & & & \\ & & & & CH_3 & & & & & \leftarrow \text{Methyl group on Carbon-2} \end{array}$$

2-methylbutanal

Amides

- <u>Amide</u>: an organic compound which has a "**– $CONH_2$**" group usually at the end of a hydrocarbon chain

- The $CONH_2$ group maybe shown as the following:

$$\begin{array}{c} O \\ \| \\ -C-NH_2 \end{array}$$

- They have a general formula of $\mathbf{C_nH_{2n+1}CONH_2}$

Properties of Amides

- Polar molecules and good solvents

- The amide group forms the backbone of all protein molecules (links individual amino acid subunits together)

- Can be used to form synthetic polymers

Naming Amides

- Use an ending of "**anamide**" for the parent chain when naming amides **(<u>Note</u>: the carbon in the $CONH_2$ group is included in the parent chain!)**

- Since the $CONH_2$ group is found on the **end** of a hydrocarbon chain, the **position** of the $CONH_2$ group can be **omitted** from the parent chain name.

Example:

$CH_3 - CONH_2$

Ethanamide

Example:

$$\begin{array}{lllllll} & & & O & & & \\ \mathbf{4} & \mathbf{3} & \mathbf{2} & \| & & & \\ CH_3 - & CH - & CH_2 - & C & - NH_2 & \leftarrow & \text{Butanamide parent chain} \\ & | & & \mathbf{1} & & & \\ & CH_3 & & & & \leftarrow & \text{Methyl group on Carbon-3} \end{array}$$

3-methylbutanamide

Ketones

- <u>Ketone</u>: an organic compound which has a "**– CO –**" group in the hydrocarbon chain (not at the ends!)

- The CO group maybe shown as the following:

```
  O
  ||
– C –
```

- They have a general formula of $\mathbf{C_nH_{2n}O}$ (same as aldehydes)

Properties of Ketones

- Similar properties as Aldehydes

Naming Ketones

- Use an ending of "**anone**" for the parent chain when naming ketones **(<u>Note</u>: the carbon in the CO group is included in the parent chain!)**

Example:

```
         O
         ||
CH3 – C – CH3    ← Propanone parent chain with the CO group on Carbon-2
1        2    3
```

2-propanone (known as Acetone – common ingredient in nail polish remover)

Example:

```
         O
1        ||   3        4       5
CH3 – C – CH2 – CH – CH3    ← Pentanone parent chain with CO group on
         2              |              Carbon-2
                       CH3  ← Methyl group on Carbon-4
```

4-methyl-2-pentanone

Amines

- Amine: an organic compound containing a "**– NH_2**" group
- They have a general formula of $\mathbf{C_nH_{2n+1}NH_2}$

Properties of Amines

- They are **organic bases** and react with acids
- Smelly compounds (tend to have a fish-like odour)

Naming Amines

- Use an ending of "**anamine**" for the parent chain when naming amines

Example:

$$\overset{\mathbf{3}}{CH_3} - \overset{\mathbf{2}}{CH_2} - \overset{\mathbf{1}}{CH_2} - NH_2$$

← Amine group attached to a propane parent chain on Carbon-1

1-propanamine

Example:

$$\overset{\mathbf{4}}{CH_3} - \underset{\displaystyle CH_3}{\overset{\mathbf{3}}{CH}} - \overset{\mathbf{2}}{CH_2} - \overset{\mathbf{1}}{CH_2} - NH_2$$

← Amine group attached to a butane parent chain on Carbon-1

CH_3 ← Methyl group on Carbon-3

3-methyl-1-butanamine

Ethers

- Ether: an organic compound in which an **oxygen** joins two hydrocarbon groups together
- The oxygen atom maybe shown as the following:

$$- O -$$

- They have a general formula of $\mathbf{C_nH_{2n+2}O}$

Properties of Ethers

- Tend to be quite **unreactive** molecules
- Good solvents
- Some ethers (eg. Diethyl ether) are used as an **anaesthetic** in hospitals on people and by biologists on animals and insects

Naming Ethers (Note the following exceptions:)

- Consider the **oxygen** atom in the ether group to be the **parent chain** and use the name "**ether**"
- Treat the **two** hydrocarbon chains attached to the oxygen atom as **alkyl side chains** and name them in alphabetical order with **spaces** in between each side chain.

Example:

$CH_3 - O - CH_2 - CH_3$ ← Methyl and ethyl side chains attached to the oxygen

Ethyl methyl ether

Example:

$CH_3 - O - CH_3$ ← Two methyl groups attached to oxygen

Dimethyl ether

In Organic Chemistry, you will come across molecules that contain **more than one type** of functional groups. In that case, you will have to **determine** which functional group has the **highest priority** in naming by using a functional groups **naming chart**. You <u>will not</u> be expected to do this in Chemistry 11 but for future reference, the following chart is provided.

Chemistry 11 – Functional Groups Naming Chart

Highest Priority

Functional Group	Formula	General Equation	Example	Nomenclature
Carboxylic Acid	O ‖ – C – OH	$C_nH_{2n+1}COOH$	O ‖ CH_3-CH_2-C-OH Propanoic acid	**- anoic acid** (pos. # not rqd!)
Ester	O ‖ – C – O –	$C_nH_{2n+2}COO$	O ‖ CH_3-CH_2-C-O-CH_3 Methyl propanoate	**- anoate** (alkyl group on oxygen atom)
Amide	O ‖ – C – NH_2	$C_nH_{2n+1}CONH_2$	O ‖ CH_3-CH_2-C-NH_2 Propanamide	**- anamide** (pos. # not rqd!)
Aldehyde	O ‖ – C – H	$C_nH_{2n}O$	O ‖ CH_3-CH_2-C-H Propanal	**- anal** (pos. # not rqd!)
Ketone	O ‖ – C –	$C_nH_{2n}O$	O ‖ CH_3-CH_2-C-CH_2-CH_3 3-pentanone	**- anone**
Alcohol	– OH	$C_nH_{2n+1}OH$	CH_3-CH_2-CH_2-OH 1-propanol	**- anol**
Amine	– NH_2	$C_nH_{2n+1}NH_2$	CH_3-CH_2-CH_2-NH_2 1-propanamine	**- anamine**
Ether	– O –	$C_nH_{2n+2}O$	CH_3-O-CH_2-CH_3 Ethyl methyl ether	**- ether** (alkyl alkyl ether)
Alkene	C = C	C_nH_{2n}	CH_2=CH-CH_2-CH_3 1-butene	**- ene** [cis/trans isomers]
Alkyne	C ≡ C	C_nH_{2n-2}	CH≡C-CH_2-CH_3 1-butyne	**- yne**
Alkane & Alkyl Halides	C – C F,Cl,Br,I	C_nH_{2n+2}	CH_3-CH_2-CH_2-Cl 1-chloropropane	**- ane**

Lowest Priority